IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 18, Issue 5, Ver. V (Sep. - Oct. 2016), PP 08-16
www.iosrjournals.org

Steady State Analysis Of The Power System Of A Building Incorporating A 6kw Photovoltaic System Interconnected To The Grid

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Abstract:*This work describesasteady state analysis of a building with a 6 kW photovoltaic system interconnected to the grid. Thebuilding is"Centro de Investigación de los Programas de Ingeniería – CIPI" at Universidad de Bogotá Jorge Tadeo Lozano, in Bogotá, Colombia. The photovoltaic system is installed on the building's roof and it has been operating properly since the month of January 2015. Steady state analysis is performed using the ETAP™ software, with which the following types of analyzes were performed: power flow, short circuit study and harmonic analysis. The results indicate that the active power and reactive power of bus 1are within the permitted limits (48 kW, 30 kVAR); short circuit tests meet the standard ANSI C37/UL489 and the total harmonic distortion%THD does not exceed the limits permitted by the standard IEE 929-2000.*
Keywords: *power system analysis, simulation, photovoltaic system.*

I. Introducción

Nowadays, a new concept of electrical power systems called Smart Grids requires several investments to transform the electrical systems that provide modern technologies to generate, transmit and principally distribute electrical energy systems [1, 2].

The smart grid concept is based on an intense usage of automation, computation and telecommunication technologies to monitor and control electrical systems that allow the implementation of new control, communication, protection and optimization strategies to improve the efficiency of the currently available systems [2, 3].

One of the main objectives in the distribution system analysis isthe development of methodologies that are able to represent electricalsystems in detail, considering their different topologies andthe variety of equipment present in these systems, especially inthe context of smart grids [4-10].

The application of advancedmethodologies allows engineers to achieve better operating conditionsand plan more effectively [11].

Some authors have proposed specific methodologies for faultanalysis in distribution systems, thereby improving some aspectsof the analysis [12-21].

The electrical system needs to remain at all times in a state of equilibrium,where the generation meets demand instantly, and where their most important variables do not exceed specific limits.The system operator is responsible for maintaining the correct operation through coordination between generation, transmission and distribution for the supply of electricity is done safely, reliably and with the required quality [22,23,24].

The stability of a power system is defined as the system capacity, for a given initial condition, to recover a normal equilibrium state after being subjected to a disturbance [25,26].

There are several studies about photovoltaic energy in Colombia [27,28,29] and this one is intended to improve the electrical analysis and its impact on the grid.

The purpose of this work is to determine through simulations the behavior in steady state of the electrical system of the building, incorporating a photovoltaic generator of 6 kWin the main building distribution board. For this we use ETAP™ software version 12.6.0,which is a tool of analysis, design, simulation and operation of power systems.The simulations were the following: power flow, short circuit study and harmonic analysis.

II. SystemDescription

2.1 Building Integrated Photovoltaic System - BIPVS

The grid – connected BIPV system installed at the Universidad de Bogotá Jorge Tadeo Lozano includes a PV-array of 24 modules of poly-crystalline silicon (Trina Solar TSM-PA05.08), each one of 250 Wp and an inverter Sunny Boy 5000-US model of 5000 W. Taking into account that the DC input of the SB 5000-US inverter varies between 175 and 480 V and the voltage at maximum power point (VMPP) of the module is 38V, the PV array was built interconnecting 2 branches in parallel of 12 modules in series each one (see Figure 1). Under these conditions the nominal power of the PV array is 6000 Wp.

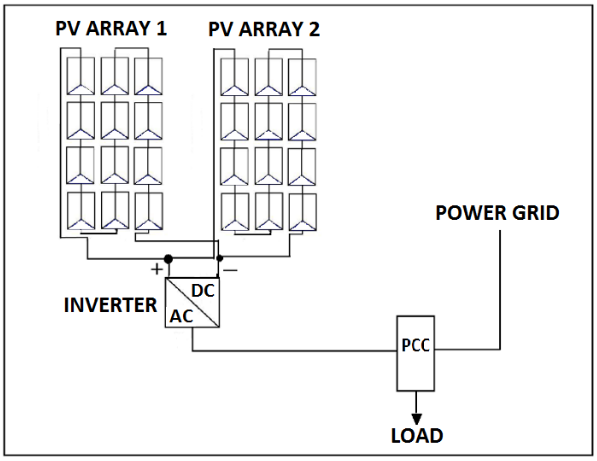


Figure 1. Diagram of the BIPV system

Table 1 shows the data sheet of the PV modules used for testing the simulation method developed in this work.

Electrical Data - STC	
PV MODULE	**TRINA SOLAR TSM-PA05.08**
Nominal Maximum Power (Pmax) [W]	250
Optimun Operating Voltage (Vmp) [V]	30.3
Optimun Operating Current (Imp) [A]	8.27
Open Circuit Voltage (Voc) [V]	38
Short Circuit Current (I sc) [A]	8.79
Module Efficiency (η) [%]	15.3
Open Circuit Voltage (Voc) [V]	35.2
Short Circuit Current (I sc) [A]	7.1

Table 1. Electrical specifications of the PV module

2.2 Power flow analysis

The concept of power flow is associated with the prediction of the direction of flows in the network, voltages and powers, which allow assessing the state of the network in advance and provide an inadequate situation in the system. In general, the power flow is a basic tool to determine the conditions of steady-state operationof a power system [25].

The load flow is performed for planning, design and operation of power systems under various operating conditionsand to study the effects of changes in configurations on equipment, plus contingency analysis, optimal dispatch, stability, among other studies [26,27].

A load flow calculation determines the state of the power system for loading and distribution of generation given. This represents a steady state condition as if that condition had to be kept fixed for some time. The load flow problem can be defined as the calculation of active and reactive power flowing in each branch and the magnitude and phase angle of the voltages of each bus in a power system [26,27].

2.3 Short circuit analysis

A failure is defined as the flow of electric current from an energized conductor “phase” to earth or neutral conductor. When this happens, a study of the impedances of the elements that caused the fault is required [28].

Because the short circuit causes changes in the magnitude of a power system, is necessary to conduct a study to check for sizing and protective devices (switches, circuit breakers), also determine efforts and influence are subjected the system components to a short circuit in a specific area [29].

Studies about faults in a circuit have led to show great interest in their calculation, because they are causing high currents, brownouts, overheating and instability of the electrical system. Calculating short-circuit failure is very important as they help the power selection switch, since they must withstand the magnitude of high currents [30].

2.4 Harmonic distortion analysis

Power Quality in our Colombian territory, must meet regulations for the network operatorand end users that are connected to the power grid. The power quality may be quantified technically through the following parameters: Waveform, frequency, symmetry, reliability, flicker voltage, distortion power, among others.

IEEE 929-2000 standard, stablishes that the total harmonic distortion should be less than 5%of the fundamental frequency relative to the inverter output.

III. Results and discussion

3.1 Single-line diagram of the power system

The line diagram shown in Figure 2corresponds to the actual electrical system implemented in the building “CIPI” at Universidad Jorge Tadeo Lozano (UJTL)in Bogota.

The power system comprises a connection point or external network at a voltage level of 11400V, feeding a pad-mounted transformer of 75KVA, 11400/208V, exclusive use of UJTL. The low voltage cable has a length of 60 meters, size 3x4/0F+1x4/0N+1X2T THHN, a photovoltaic generator of 6,2 kW, and an inverter of 5 kW. The inverter output reaches a common bus(PCC);which also joins the transformer output, which in turn supports the entire system load.

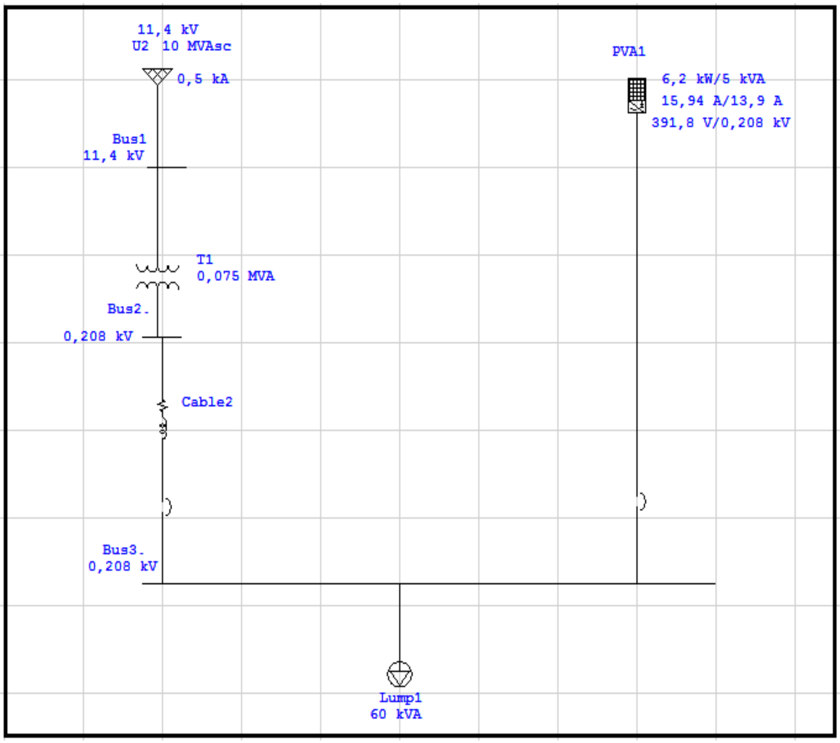


Figure2. Line Diagram of Power System of the building “CIPI” - UJTL

1.2 Load flowanalysis

Figure 3 shows the electrical system under simulated load flow parameter in ETAP software.

The data provided by the program indicate that the voltage level at medium voltage present on the bus1remains constant with 11400V, the active and reactive power are within the limits required by the system (48 KW and 30 KVAr), bus 2 has a voltage level of 203,5Vequivalent to a voltage drop of 2.16% from the initial reference voltage(208V), the active and reactive power at this point has the following values:47 KW and 29 KVAR).

The bus 3 has a voltage level of 199,1V equivalent to a voltage drop of 4,27% from the initial reference voltage(208V), the active and reactive power at the bus 3corresponds to the sum of the contribution of photovoltaic power generator (5 KW and 0 KVAr) and the initial electrical system (47 KW and 29 KVAr) for a power demanded by the system of 52 KW and 60 KVA.

This indicates that the system is operating within the requirements of voltage levels on the buses and active and reactive power in each branch of the system meet the requirements of the standard IEEE 929-2000. As for the quality parameters of power, the effective value of the voltage should be kept as stable as possible (low voltage +5% and –10%; medium voltage +5% and –10%) and power factor greater than 0.85.

To improve and correct the voltage level at bus 3, is advisable to change the position of thetransformer’s tap.

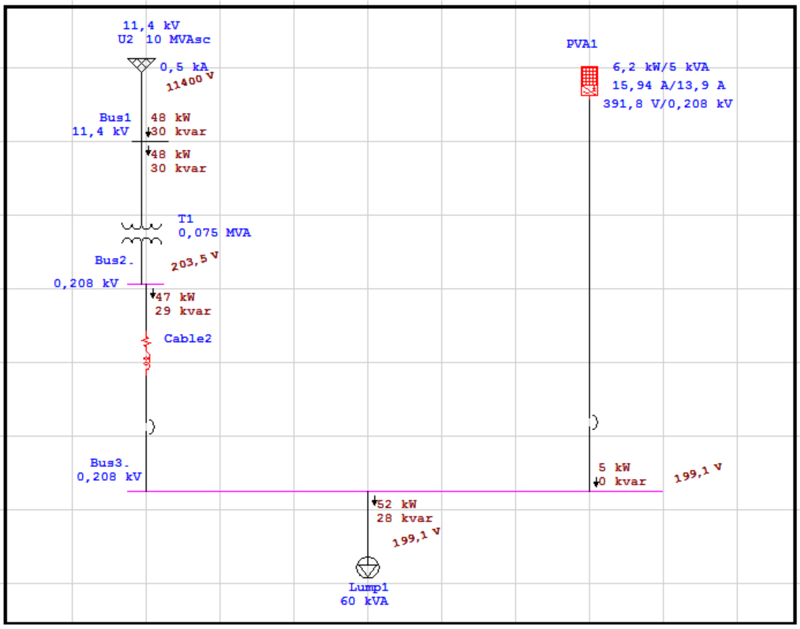


Figure3. Load flow simulation.

3.3Short circuit analysis

An analysis is made for different tests of three-phase fault that can be present in the electric power system.The simulations are made under the standard ANSI C37/UL489.

Test 1:

Three-phase fault on bus 1: As shown in Figure 4, the voltage level becomes zero at this pointand the generated current faultreaches 0,515 KA, affecting the buses 1 and 2 with instantaneous voltage drops of 0,019 kV and 0,033 kV.

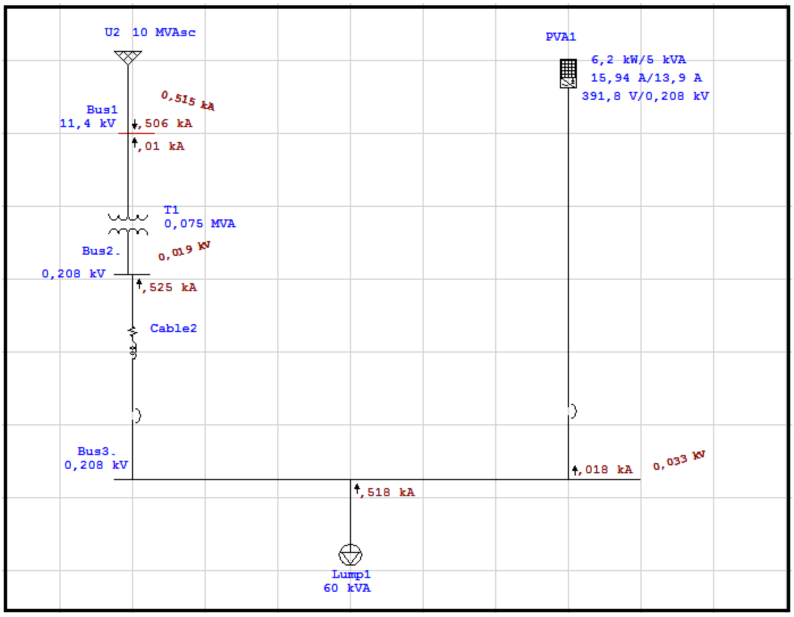


Figure 4. Three phase short circuit simulation at bus1.

Test 2:

Three-phase fault on bus 2: As shown in Figure 5, the voltage level becomes zero at this pointand the generated current faultreaches 5,3 KA, affecting the bus 1 with instantaneous voltage drops of 9,514 kV and a current flow of 0,086 KA. The same effect occurs in the bus 3with an instantaneous voltage of 0,016 kV and a current flow of 0,552 KA.

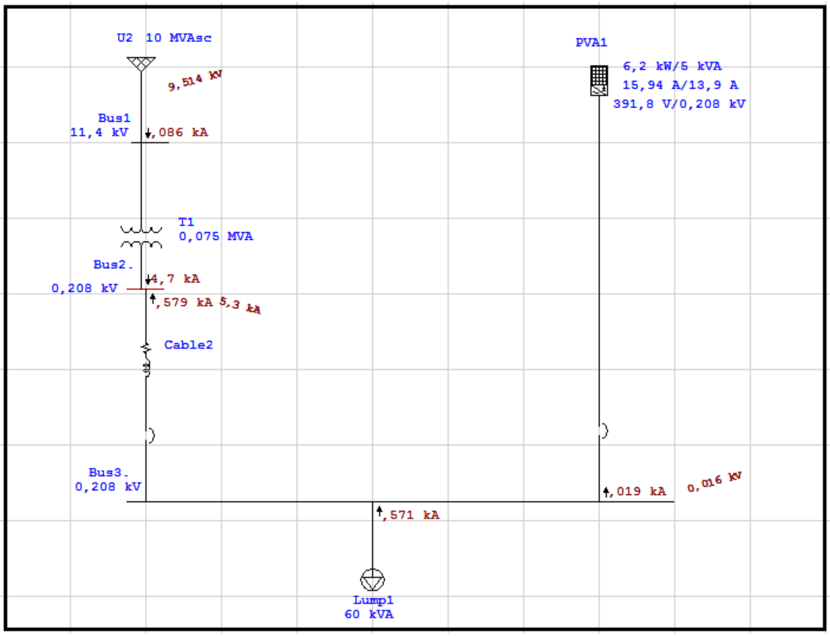


Figure 5. Three phase short circuit simulation at bus 2.

Test 3:

Three-phase fault on bus 3:As shown in Figure 6, the voltage level becomes zero at this pointand the generated current faultreaches 3,6 KA, affecting the bus 2 with instantaneous voltage drops of0,084 kV.The same effect occurs in the bus 1 with an instantaneous voltage of 10,288 kV and a current flow of 0,55 KA.

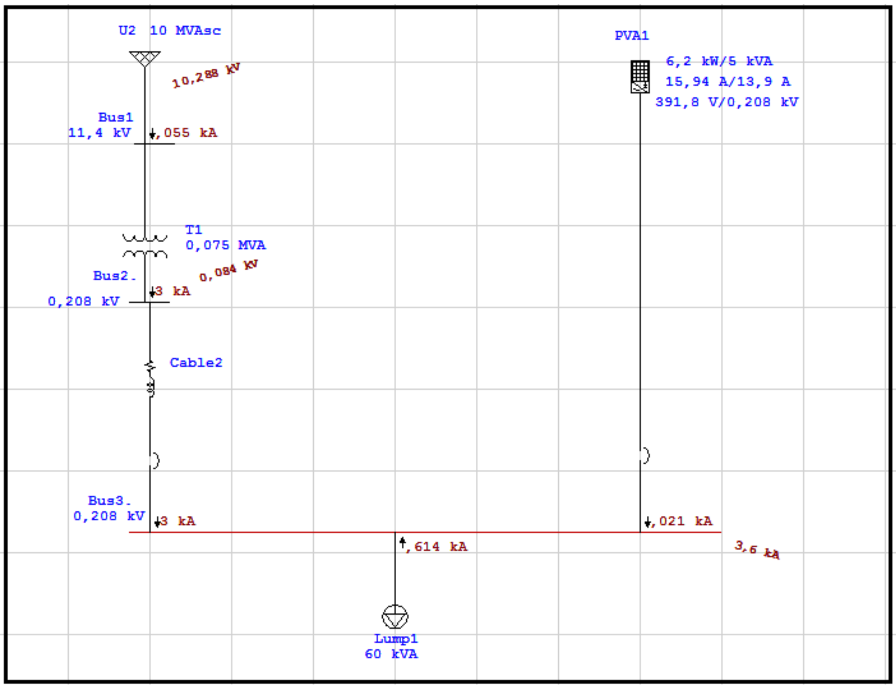


Figure6. Three phase short circuit simulation at bus 3.

3.4 Harmonics distortion analysis

In the single-line diagram of Figure 7, the case study of harmonic analysis is simulated by the method of Newton Rapson, with a maximum of 99 iterations and a precision of 0,0001.The harmonic model usedwasThevenin / Norton Equivalent for all Sources (recommended by the software).

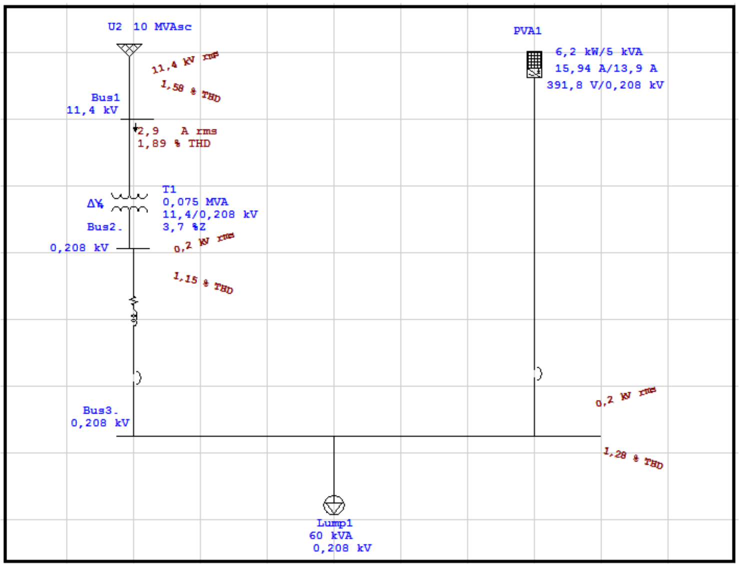


Figure7. Total harmonic distortion THD simulation.

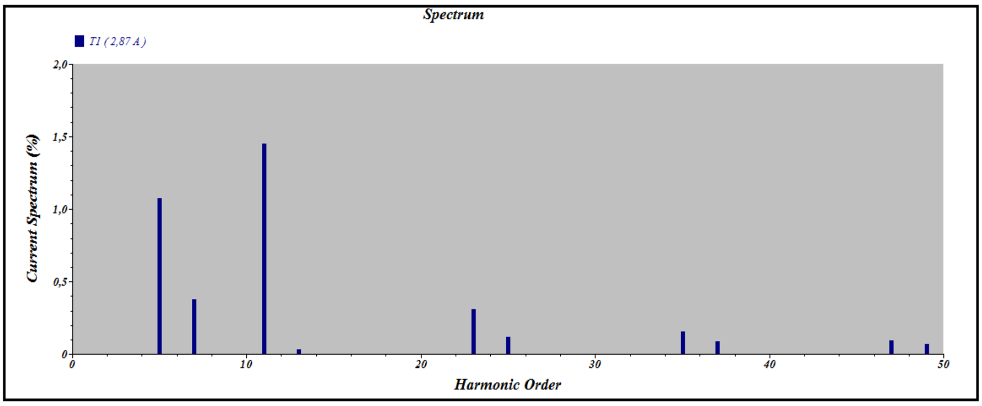
The results indicate that instantaneous voltage levels are stable in the bars 1, 2 and 3: 11,4 kV; 0,208 kV and 0,208 kV respectively. Total harmonic distortion at the same points was: 1,89%; 1,15% and 1,28%.

Test 1:

%THDi - transformer: Figure 8 shows the spectrum with the harmonic components of currents and wave current flowing through the transformer of 75 KVA.The components of harmonic current of greater magnitude are odd order components 5, 7, 11, 13 whose values are reflected in Table 2.

#	X	Y1
0	1	0
1	3	0
2	5	1,07618
3	7	0,378238
4	9	0
5	11	1,45242
6	13	3,12448e-
7	15	0
8	23	0,312819
9	25	0,119864
10	35	0,159304
11	37	8,78309e-
12	47	9,34906e-
13	49	6,89945e-

Table2. Odd harmonic current components in the transformer of 75 KVA.



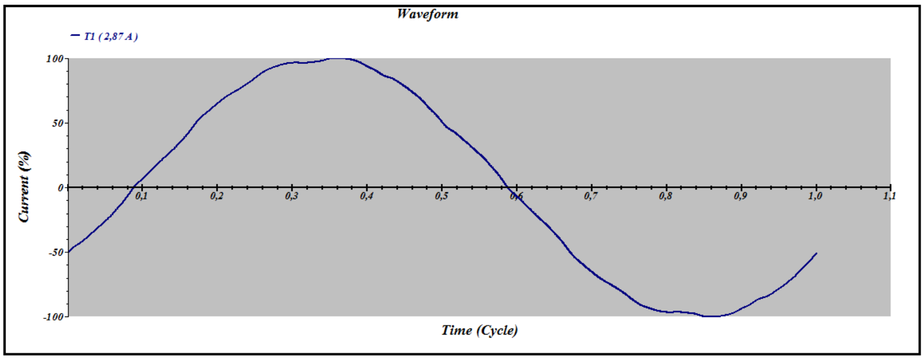


Figure8. Harmonic spectrum of currentin the transformer.

Test 2:

%THDvin buses 2 and 3: Figure 9 shows the spectrum of the harmonic components of voltage and voltage waveform of the buses 2 and 3. The harmonic voltage components of greater magnitude in the bus 2are odd order components 11, 13, 23, 25, 35 and 37.Harmonic components of the bus 3 are almost identical to the bus 2, the values of these components are reflected in Table 8.

#	X	Y1	Y2
0	1	0	0
1	3	6,52885e-	6,06968e-
2	5	0,230442	0,224389
3	7	0,142039	0,138061
4	9	1,85227e-	1,67663e-
5	11	0,463191	0,500768
6	13	0,550601	0,618316
7	15	2,24468e-	1,94647e-
8	23	0,411653	0,478728
9	25	0,474149	0,490877
10	35	0,284787	0,327876
11	37	0,331611	0,329713
12	47	0,20025	0,225558
13	49	0,232904	0,221308

Table3. Harmonic voltage components in buses 2 and 3.

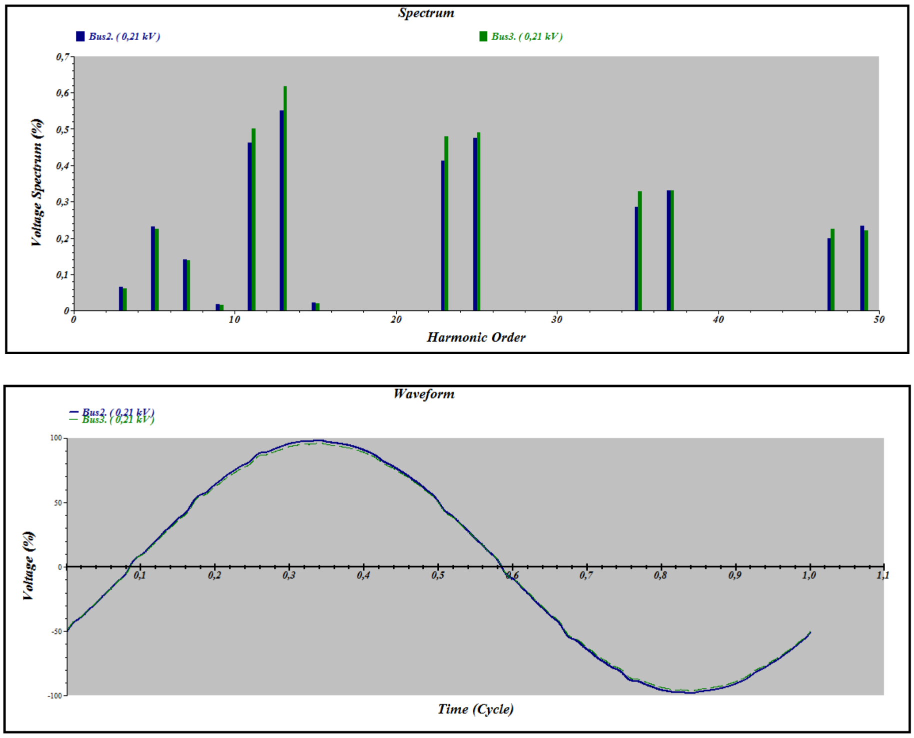


Figure9. Harmonic spectrumof voltage in the buses 2 and 3.

IV. Conclusion

A power flow calculation determines the state of the system for a load and generation given in steady state condition. Developed simulation allows predicting the steady state electrical performance of the power system incorporating a photovoltaic generator of6 kW in the building of Universidad Jorge Tadeo Lozano.

Basically to determine the conditions of steady-state operation; the conditions of load flow, short circuit currents and harmonic distortion of the power system are analyzed.

The results analyzed and simulated by software ETAP 12.6.0, indicate that the system is operating within the requirements of voltage levels in buses, generation of active and reactive power, selectivity of protective equipment and harmonic distortion; according to IEEE 929-2000 and IEEE 519-1992.

The implementation of computational tools described,are a contribution to enhance studies, enabling a greater amount of analysis elements that are useful for support in decision making and drawing conclusions in a simulated operating scenario.

Acknowledgements

This work was carried out with the financial support of the researching project 633-11-14 from Universidad de Bogotá Jorge Tadeo Lozano.

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